UNEVEN-COUNTER-ROTATIONAL COIL BASED MRI RF COIL ARRAY

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional patent application Serial No. 60/273,092 filed March 2, 2001.

BACKGROUND OF THE INVENTION

Magnetic resonance imaging (MRI) relies on the detection of the MR signal from abundant protons in the human body. A radio frequency (RF) receive coil is a device to effectively "pick up" the MR signal from the background of noise for image production. MR signals induced in a RF receive coil are weak signals due to the very small population difference between the two relevant proton energy states at room temperature. One of the challenges in RF coil design is to improve the MR signal detection sensitivity.

One of the approaches to improve signal detection sensitivity and/or field of view is to use multiple receive coils as an array. The basic idea is that instead of making a larger and less sensitive coil that covers the entire volume of interest, plural smaller and more sensitive coils are distributed over the volume of interest. Each individual coil picks up signal and noise from a localized volume. With separate detection circuitry, each coil element receives the image signal simultaneously. Signals from all the coils are finally combined and processed to reconstruct the MR image for the entire volume of interest.

The principle of MRI involves exciting protons and detecting the resulting free induction decay signals. Each proton possesses a tiny magnetic moment precessing about the static

magnetic field. The macroscopic behavior of millions of protons can be represented by a resultant magnetization vector aligning with the static magnetic field B_0. A strong RF excitation pulse effectively tips the magnetization away from B_0. The free induction decay of this magnetization is detected in a plane perpendicular to B_0. Thus, for maximal signal induction, the normal direction of a receive coil must be perpendicular to the direction of the static magnetic field B_0.

Based on the direction of static magnetic field, commercial MRI systems are either horizontal or vertical. The so-called co-planar type coil arrays have proved to be effective for horizontal MRI systems for the reasons discussed in the previous paragraph. In a co-planar array, surface coils are arranged in a co-planar fashion and distributed over a volume of interest.

In general, such co-planar type surface coil arrays are not very effective for a vertical system because the condition required for maximal signal induction can hardly be fulfilled. Various modifications to the co-planar designs have been proposed with limited success.

It is known that solenoidal type coils have several advantages for a vertical field system, including its sensitivity, uniformity and its natural fit to various body parts. It is advantageous to utilize solenoidal based coil arrays for vertical MRI systems.

To successfully implement a solenoidal coil array, one must be able to isolate solenoidal coils of the array to prevent them from coupling to each other. This is required because all coils in a coil array typically receive signals simultaneously. "Cross-talk" between different coils is undesirable. Thus effective coil isolation is a major challenge in solenoidal coil array design.

A so-called sandwiched solenoidal array coil (SSAC) has been

set forth in U.S. Patent Application No. 09/408,506. A SSAC consists of two solenoidal receive coils, a counter-rotational solenoidal coil and a second solenoidal coil sandwiched between the two counter-rotational winding sections of the first coil.

The counter-rotational solenoidal coil produces a gradient B1 field that has a double-peak "M" shape sensitivity profile. The second solenoidal coil produces a single-peak profile sandwiched between the two peaks of the "M" shape profile of the first coil.

The sensitivity profile of a SSAC is determined by the summation of an "M" shape double-peak profile and a centralized single-peak profile generated by the two coils. To avoid unwanted dark band artifacts in the array coil sensitivity profile, the geometric parameters of both coils must be set properly. This process is sensitive to the geometries at hand.

SUMMARY OF THE INVENTION

A MRI RF coil array is formed from a first coil having a null B_1 point and a quasi-one-peak sensitivity profile, and a second coil oriented with respect to the first coil to reduce coupling.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an uneven-counter-rotational solenoidal coil.

FIG. 2 is a graphical diagram of exemplary B1 and sensitivity profiles of an uneven-counter-rotational solenoidal coil according to the invention.

FIG. 3 is a graphical diagram of an exemplary sensitivity profile of a coil array according to the invention as a

superposition of two individual solenoidal coils.

FIG. 4 is a schematic diagram of a coil array according to the invention in a cascade configuration.

FIG. 5 is a schematic diagram of a coil array according to the invention in an overlapped configuration.

FIG. 6 is a schematic diagram of a coil array according to the invention in a sandwiched configuration.

FIG. 7 is a schematic diagram of an embodiment of the invention showing spacing parameters.

FIG. 8 is a graphical diagram of an exemplary coupling sensitivity between the two coils of the array of FIG. 7.

FIG. 9 is a graphical diagram of a B1 profile for coil array of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, an uneven-counter-rotational (UCR) coil 12 is illustrated. The coil 12 is formed from a first coil section A and a second coil section B. Section A has more turns than section B, for example, 3 verus 1. Section B is wound in the opposite direction from section A. For example, section A has three turns with the current flowing in the same direction and section B has one turn with current flowing in a counter-rotational direction. The separation between the neighboring turns is denoted as S12, S23 and S34, respectively. In general, the turn separation and diameter parameters may have different values depending on the specific coil design needs.

For example, the parameters may be as follows: S12=8cm, S23=7cm, S34=10cm and D=26.7cm. FIGS. 2a and 2b show the B1 field produced by the sections A and B, respectively. FIG. 2c shows the total B1 field produced by the UCR solenoidal coil 12. The sensitivity profile is shown in FIG. 2d. It can be seen from

FIG. 2d that the UCR coil 12 generates a null-B1 point near location N and a quasi-one-peak sensitivity profile.

Referring to FIGS. 4, 5 and 6, a second solenoidal coil 14 may be placed near the null-B1 point to form a solenoidal array with the UCR coil 12 while achieving good isolation between the two solenoidal coils 12, 14. In practice, an additional isolation capacitor may be used for the convenience of fine isolation adjustment if needed.

The second solenoidal coil 14 may, for example, be formed of multiple turns as needed. The number of turns and the separation between neighboring turns can be chosen to give a desired sensitivity profile and B1 strength. The corresponding sensitivity profile of the coil 14 partially overlaps with the profile of the UCR coil 12 to determine the sensitivity of the solenoidal coil array. FIG. 3 shows an example of a solenoidal coil array profile as the summation of the two solenoidal coils 12, 14. FIG. 3 shows an artifact free array profile and the advantage of a quasi-one-peak UCR sensitivity profile design. A quasi one-peak profile for the UCR solenoidal coil 12 can be achieved by intentionally making the two peaks in the typical "M" shape profile uneven, i.e. the B1 field produced by one winding section of the UCR coil element is much stronger than the other. At the same time, the null-B1 point is retained in the quasi-one-peak profile, which is the basis for the inherent decoupling of the two solenoidal coils 12, 14. This can be accomplished by properly choosing the number of turns, their diameters and locations for each of the two winding sections.

A better understanding of the uneven-counter-rotational design, its quasi-one-peak profile and coil isolation between the two solenoidal coils of the array can be achieved by a closer look from the electromagnetic field point of view. First, the three turns in section A of the UCR coil 12 generate a strong B1

field as shown in FIG. 2a. The B1 field decreases gradually along the axis away from the section center. In fact, it approaches zero B1 at infinite distance from the center. If one would introduce a second solenoidal coil in a short distance from the section center, one would encounter strong coupling between the two coils.

Section B generates a B1 field of opposite direction to that of section A. Section B generates a negative B1 field of smaller peak value and different profile shape than that by section A. At certain location, the B1 field generated by sections A and B may cancel, forming a null-B1 point in the combined B1 profile of this UCR coil as shown in Figure 2c. By definition, the solenoidal coil 14 introduced to the location where the B1 field generated by sections A and B of the UCR coil 12 cancel experiences no magnetic coupling with the UCR coil 12. The null-B1 point can be set to be outside the UCR sections A, B, between the two UCR sections A, B or overlapped with one of the UCR sections.

The B1 field generated by the counter-rotational section B may cancel that by element A at different locations along the axis depending on relative field strength. Accordingly, the solenoidal coil array may have cascaded 10 (FIG.4), overlapped 10' (FIG. 5) or sandwiched 10'' (FIG. 6) configurations depending on if the second solenoidal coil 14 is outside the UCR solenoidal coil 12, overlapped with section B of the UCR coil 12 or inside the UCR coil 12, respectively. In any case, the solenoidal array is UCR-based and is conceptually different from and more advanced than the previous "sandwiched solenoidal array" due to the advantages associated with the quasi-one-peak profile feature of the UCR design.

In a UCR-based solenoidal array, each coil is subjected to noise pickup from a smaller region just like other types of array

coil. The array coil advantages in terms of signal to nose ratio and field of view improvement applies to the UCR solenoidal array as disclosed in this invention.

A prototype UCR solenoidal array was built to prove the concept. The prototype solenoidal array coil included a UCR solenoidal coil and a 2-turn solenoidal coil. The solenoidal coil array was built for a 0.3T Hitachi Airis II imaging system at the resonance frequency of 12.687 MHz.

The coil traces were made of 0.2 mm thick, 10 mm wide, copper strips wound on a 267 mm diameter acrylic tube. The two solenoidal coils of the array were in overlapped configuration, meaning that the 2-turn solenoidal coil 14 overlaps with the section B of the UCR coil 12. The geometric parameters are shown in FIG. 7. The coils 12, 14 are shown on separate axes for ease of understanding.

The two solenoidal coils 12, 14 are inherently decoupled. Excellent isolation was achieved between the two coils without any additional isolation circuitry. The transmission parameter S21 is-28dB at resonance frequency, as shown in FIG. 8.

The B1 field along the axial direction was measured for each solenoidal coil alone, with the other coil active. The results are shown in FIG. 9. Also shown is the combined solenoidal array B1 profile. The UCR solenoidal coil 12 has a quasi-one-peak profile with a null-B1 point residing at about the middle of the coil 14 profile. The summation of individual profiles gives a nice total array profile without artifacts.

The array coil of the invention need not be just solenoidal coils. For example, an orthogonal coil element, such as a saddle coil, may be added to form a quadrature pair with each solenoidal coil. Therefore, a two-solenoidal coil array can be easily developed to be a two-quadrature-pair solenoidal array coil to take advantage of quadrature effect in signal to noise ratio

improvement.

It should be evident that this disclosure is by way of example and that various changes may be made by adding, modifying or eliminating details without departing from the fair scope of the teaching contained in this disclosure. The invention is therefore not limited to particular details of this disclosure except to the extent that the following claims are necessarily so limited.